Predictability of Particle Trajectories in the Ocean

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LONG-TERM GOALS

The long term goal of this project is to determine optimal sampling strategies for drifting buoys, in order to enhance prediction of particle motion in the ocean, with potential applications to ecological, search and rescue, floating mine problems, and design of observing systems.

OBJECTIVES

To develop methods for the objectives of ODDAS DRI, which is to preserve the sampling volume of an acoustic sensor array, and replenish when gaps in the observational volume occur due to the dispersion of the sensors with the underlying Eulerian flow field.

APPROACH

The work is based primarily on stochastic and dynamical models of particle motion and data assimilation strategies. It also involves the use of coastal circulation models and processing of oceanic data such as drifter positions, ocean surface currents, and wind field.

WORK COMPLETED

1) Publication of the Lagrangian Analysis and Predictability of Coastal and Oceanic Dynamics (LAPCOD) book by the Cambridge University Press.

2) Publication of three papers (Caglar et al., 2006; Haza et al., 2007a; Chin et al., 2007) for which most of the research was carried out during the previous grant year, but their revision still required some effort and time.

3) Analysis of targeted drifter trajectories from the winter cruise of the DART (Dynamics of the Adriatic in Real Time) observational program, and publication of a paper (Haza et al., 2007b).

4) Analysis of relative dispersion from synthetic drifter trajectories derived from

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the Navy Coastal Ocean Model (NCOM) configured in the Adriatic Sea, and submission of a manuscript.

RESULTS:

1) *Results from targeted drifter launch strategies during DART:*

PIs (Griffa, Özgökmen) and postdoc (Angelique Haza) have participated in the drifter release component of Dynamics of the Adriatic in Real Time (DART) experiment conducted jointly by NATO-NURC (led by Michel Rixen) and NRL (led by Jeff Book). DART involved two trials, namely DART06A in March 2006 and DART06B in August 2006. We focus on observations during DART06A here, concentrating on a set of surface drifters launched during a high resolution hydrographic ship survey. Drifter launches were specifically directed based on maxima of finite-size Lyapunov exponents calculated from the NCOM configured in the Adriatic Sea to provide two-day hind and forecasts. The specific goal was to choose positions that would maximize the particle spreading and therefore the spatial coverage of sampling. To the knowledge of the authors, this is the first time that drifter launches during an observational program have been guided in near real time based on modern coastal model output and Lagrangian techniques. A main objective of the multi-institutional DART experiment in the coastal area of the western central Adriatic is to study mesoscale instabilities arising in the Western Adriatic Current (WAC) near the Gargano Cape. A suite of different measurements were used in conjunction with a real-time modeling effort. As part of DART06A, a total of 12 surface drifters (CODE and SVP types) were successfully launched between March 11 and 23, 2006.

The main sampling goal for the drifters was to achieve a good coverage of the DART area. To this end, launches were planned in the two dynamically distinct areas namely in the WAC and along the inter-gyre boundary offshore from the Gargano Cape. The exact launch locations and times were constrained by logistical considerations including weather conditions and the pre-planned ship track. The launch locations in the WAC were determined a-priori based on historical information and required no real-time, model-based direction effort. Three directed launches were made targeting the region off-shore from the Cape. The resulting drifter trajectories provide a good coverage of the region, satisfying the general goal of the sampling strategy. This is in part due to directing drifter launches along the out-flowing branch of identifiable Lagrangian boundaries. This strategy optimizes the relative dispersion of drifters, the overall data coverage, and the sampling of high kinetic energy features in the flow field. A prerequisite for implementing this strategy is a methodical identification of the Lagrangian features.

A practical method to identify high-dispersion regions and mixing boundaries upon which to base drifter launch strategies is the computation of the Lagrangian spatial structures produced by the local, finite-size Lyapunov exponents (FSLE). Model FSLE fields were calculated from sets of 5 synthetic trajectories centered at every grid point in the NCOM model. The FSLE map of the DART region at a particular day is obtained by advecting a total of 114,250 particles both forward in time from the 2 day-forecast velocities, and backward in time from the 2 day-hind-cast velocities. Once the location of a strongly hyperbolic region was determined from isolated intersections of the FSLE fields from two-day NCOM forecasts and hind-casts, a subset of 10-20 synthetic drifters were launched in this selected area and advected by the 2-day-forecast fields as a preliminary test. Finally, 2-3 drifter launch locations were chosen to straddle the in-flowing structure and to lie as close to the out-flowing pathway as the ship-track would allow. These locations were then communicated to the ship on a real-time basis.

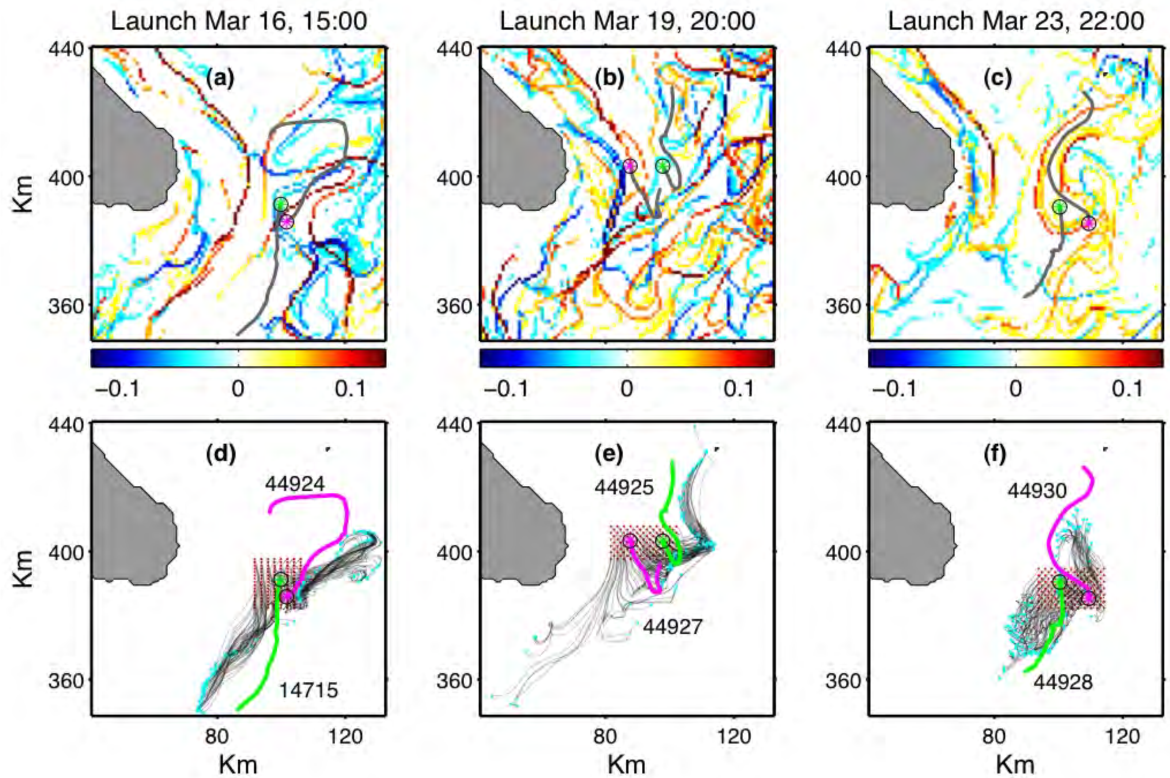

Figure 1: The initial 2-day trajectories for real (gray: upper panels, green and purple: lower panels) drifters launched on March 16, March 19 and March 23 (launch position indicated by circles). Superimposed are the FSLE computed at launch time (a)-(c), and synthetic drifters released in regular arrays (d)-(f). Red (blue) dots indicate initial (final) positions of the synthetic drifters.

Launch set 1: March 16, buoys *14715* and *44924*:
Due in part to the low-intensity winds, a well-defined hyperbolic point (HP) is visible from the FSLE map (Fig.1a). Two locations are selected along the track corresponding to the out-flowing Lagrangian branches from the HP, based on the FSLE extrema. As a result, the drifters diverged immediately and propagated in opposing directions. The success of this launch is due in part to the nearly-stationary position of the HP over the following two days, and effectively real time implementation of the suggested launch locations. The synthetic trajectories also confirm the polarized nature of the Lagrangian dispersion in the vicinity of the launch, as all synthetic particles are transported along only two out-flowing branches (Fig. 1d).

Launch set 2: March 19, buoys *44925* and *4492*:
Launch locations were initially chosen based on the model-forecasted FSLE fields for March 17, to straddle an in-flowing branch of an identified Lagrangian structure boundary near a HP with the expectations of rapid divergence of the drifter pair. But, logistical problems delayed the actual drifter launch until March 19. As shown in Fig. 1b, the model accurately predicts the rapid reaction of the flow to the changing wind conditions and the movement of strong intersections of FSLE maxima

away from the previously determined launch locations. As such, the actual drifter launch occurred in a region predicted by the model to have minimal relative dispersion.

Launch set 3: March 23, buoys *44928* and *44930*:
In this case, the deployment time was constrained by the finite extent of the observational program, with the latest possible launch date being March 24-25. While the model did not predict the presence of a strong, isolated, hyperbolic point along available ship tracks on March 23, Fig. 1c indicates the presence of a Lagrangian structure boundary in the launch region as given by distinct maxima in the backward-in-time FSLE (the red curve). The actual drifter deployment placed one drifter in the interior of this structure and the other outside. This deployment leads to advection in nearly opposite directions and a rapid separation of the observed trajectories in keeping with the overall predictions of the model (Fig. 1f). Drifter 44930 followed the pronounced northward pathway outside the model FSLE structure with remarkable accuracy (Fig. 3c). Initially the other drifter, 44928, propagated southwards with the structure as predicted by the model. The observed drifter track shows appreciable slowing before further southern propagation due to the break up of the transport barrier blocking southward pathways one day after the launch (not seen in launch time FSLE plot). This change in structure and opening of advective pathways is presumably due to the influence of the Bora wind event.

We emphasize the remarkable spatial complexity and rapid change of the model FSLE fields (Fig. 1a-c), forced and maintained mainly by winds and mesoscale turbulent coherent flow structures. While the envelope of synthetic drifter trajectories and the observed trajectories indicate significant differences, the model-derived FSLE fields (resulting from averages over both time and ensembles of trajectories) are apparently robust enough for accurate short-time prediction of the observations.

To our knowledge, this is the first time that targeted drifter launch strategies have been employed in real-time during an observational program. Overall, we conclude that the accuracy of the surface Eulerian fields from state-of-the-art operational coastal models appears to have reached a level that is adequate enough for model-based Lagrangian diagnostics to be used in real-time-directed drifter launches in observational programs.

2) Estimates of relative dispersion in the Adriatic Sea:

Synthetic drifter trajectories computed from velocity data produced by a high-resolution NCOM model are used to investigate the scaling of relative dispersion and the distribution of Finite-Scale Lyapunov Exponent fields in the Adriatic Sea. *Relative dispersion quantifies how fast particle pairs separate from one another, and thus it is a key metric for the purposes of ODDAS DRI.* The effects of varying degrees of spatial and temporal filtering of the input Eulerian velocity fields on the Lagrangian statistics are investigated in order to assess the sensitivity of such statistics to model error. It is shown that the relative dispersion in the model Adriatic circulation is generally super-diffusive, scaling nearly ballistically in close agreement with Lagrangian observations from a limited set of drifters.

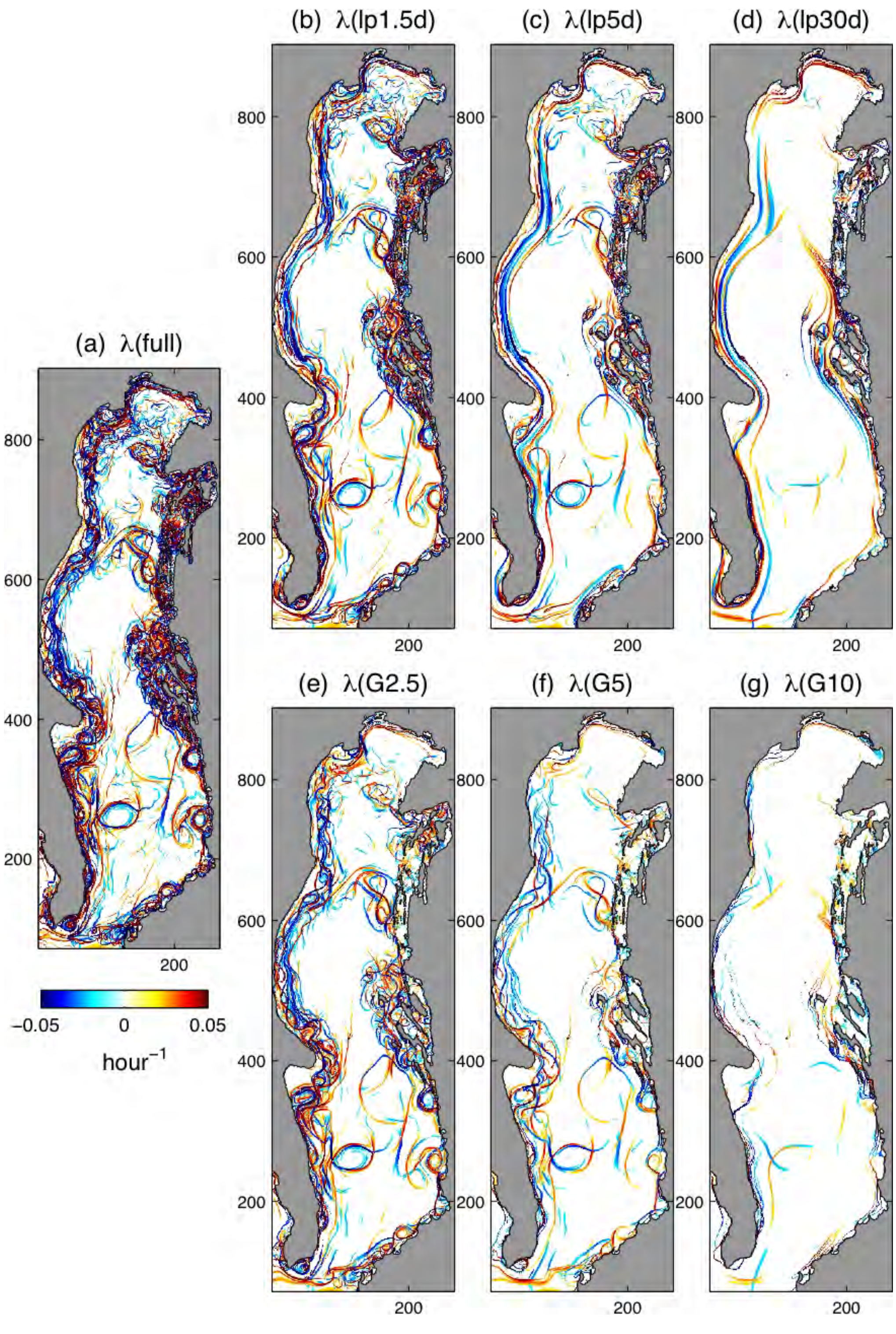

Figure 2: Spatial distribution of FSLEs forward six days in time starting from September 6, 2002 (positive) and backward six days in time (negative) calculated from (a) the raw field, (b) with 1.5-day time filtering, (c) with 5-day time filtering, (d) with 30-days time filtering, (e) with spatial smoothing filter scale of 2.5 km, (f) 5 km, and (g) 10 km.

It is found that the large-scale dispersion is dominated by persistent separation regions and the controlling influence of the Western Adriatic Current. Temporal filtering with averaging windows up to monthly time scales only affects the relative dispersion at scales smaller than 20 km without altering the overall scaling regime. In contrast, spatial smoothing at scales as small as 5 km significantly reduces relative dispersion at all scales up to 100 km. While no clear exponential regime is observed in the full data set, a distinct flattening of the FSLE curves are observed for larger-scale spatial smoothing. The role of chaotic advection in determining the small-scale relative dispersion in such cases is examined.

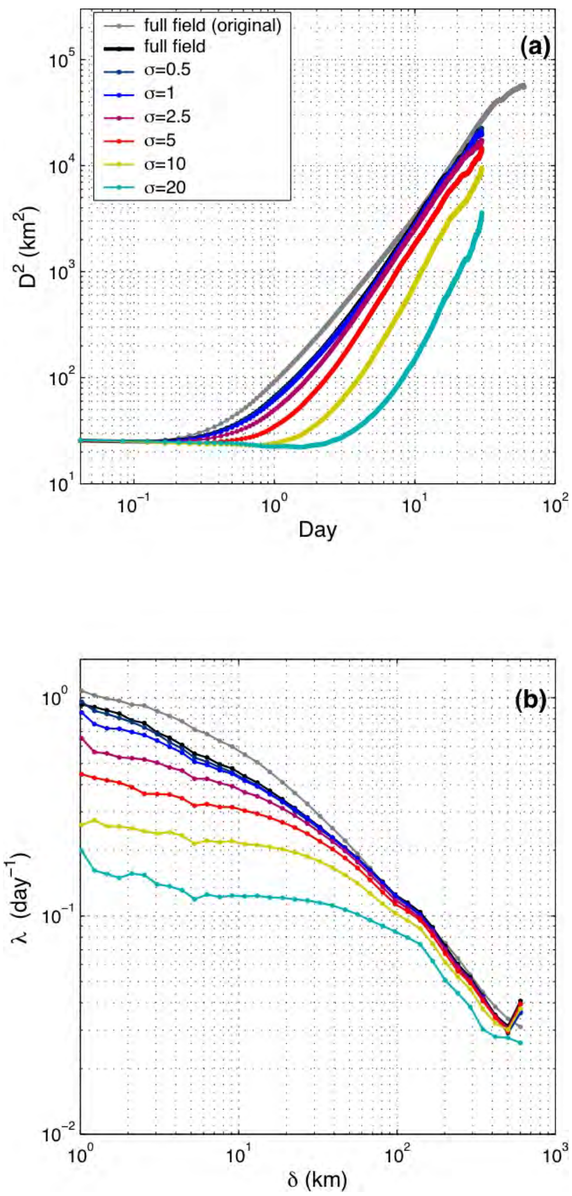

Figure 3: Effect of space-smoothing on (a) the relative dispersion, and (b) on the FSLE curve for six different values of spatial filtering parameter. The trajectories near the coastline have been discarded to avoid spurious dispersion, and the difference in relative dispersion and FSLE is highlighted by the new (black) and original (gray) full field curves.

IMPACT/APPLICATIONS

The investigation of the predictability of particle motion is an important area of study, with a number of potential practical applications at very different scales, including searching for persons or valuable objects lost at sea, tracking floating mines, ecological problems such as the spreading of pollutants or fish larvae, design of observing systems and navigation algorithms.

RELATED PROJECTS

Lagrangian Turbulence and Transport in Semi-Enclosed Basins and Coastal Regions, PI: A. Griffa, N00014-05-1-0094.

Statistical and Stochastic Problems in Ocean Modeling and Prediction, PI: L. Piterbarg, N00014-99-1-0042.

Optimal Deployment of Drifting Acoustic Sensors: Sensitivity of Lagrangian Boundaries to Model Uncertainty, PI: A. Poje, N00014-04-1-0192.

PUBLICATIONS (2006-2007)

Griffa, A., A.D. Kirwan, A.J. Mariano, T.M. Özgökmen and T. Rossby, 2007: Lagrangian Analysis and Prediction of Coastal Ocean Dynamics. Cambridge University Press, 487 pp.

Piterbarg, L.I., T.M. Özgökmen, A. Griffa, and A.J. Mariano, 2007: Predictability of Lagrangian motion in the upper ocean. In LAPCOD book, 61-78 .

Molcard, A., T.M. Özgökmen, A. Griffa, L.I. Piterbarg, and T.M. Chin, 2007: Lagrangian data assimilation in ocean general circulation models. In LAPCOD book, 172-203.

Caglar, M., T.M. Özgökmen, and L.I. Piterbarg, 2006: Parameterization of submeso-scale eddy- rich flows using a stochastic velocity model. J. Atmos. Ocean Tech., 23/12, 1745-1758.

Haza, A., L.I. Piterbarg, P. Martin, T.M. Özgökmen and A. Griffa, 2007a: A Lagrangian subgrid-scale model and application for transport improvement in the Adriatic Sea using NCOM, 2007a. Ocean Modelling, 17, 68-91.

Chin, T .M., T.M. Özgökmen, and A.J. Mariano, 2007: Empirical and stochastic formulations western boundary conditions. Ocean Modelling, 17, 219-238.

Haza, A., A. Griffa, P. Martin, A. Molcard, T.M. Özgökmen, A.C. Poje, R. Barbanti, J. Book, P.M. Poulain, M. Rixen, and P. Zanasca, 2007b: Model-based directed drifter launces in the Adriatic Sea: results from the DART experiment. Geophysical Research Letters, 34. L10605, doi: 10.1029/2007GL029634.

Haza, A., A.C. Poje, T.M. Özgökmen, P. Martin: Relative dispersion from a high-resolution coastal model of the Adriatic Sea. Submitted to Ocean Modelling (22 August 2007).